CHAPTER 10

TREE SEEDLING RESPONSES TO WASTEWATER IRRIGATION ON A REFORESTED OLD FIELD IN SOUTHERN MICHIGAN

Dale G. Brockway
Water Quality Division
Michigan Department of Natural Resources
Lansing, Michigan 48917

INTRODUCTION

In recent years, the number of municipal wastewater irrigation projects utilizing forest ecosystems for nutrient recycling and groundwater recharge has continued to grow. Land managers involved with these projects have, in the same time period, increased their demand for scientific data which better defines the capabilities and limitations of various forest species-site combinations. Smith and Evans (1977) suggested that an initial step in planning for wastewater recycling in forests was to assess the species ecological requirements in terms of water and nutrients. Identifying forest species adapted to the moisture and nutrient regimen provided by wastewater irrigation upon a specific type of forest site is a prerequisite to sound irrigation project management.

Old fields have come under the increased scrutiny of land managers as potential forest sites where plantations established near municipalities could benefit from wastewater irrigation. Old fields occupy millions of hectares in the eastern United States and are typically the target of reforestation efforts by private and public land managers. These sites have a history of agricultural management which has significantly modified their native vegetation and soil characteristics. Old fields contain a well developed Ap soil horizon supporting a diverse array of native and exotic herbaceous and woody plant species. Intense competition from these species for available water and nutrients is a major obstacle to tree plantation establishment and development. Cultural treatments such as wastewater irrigation, which supplement site water and nutrient resources, may enhance seedling survival and growth if weed competition is controlled. Weed control is particularly critical for hardwood seedlings, which are often less able than conifers to compete with established grasses and associated vegetation.

In 1974, three conifer and six hardwood tree species were planted on an old field site and irrigated with municipal wastewater. The principal study objective was by monitoring seedling survival, growth and nutrient status, to assess tree species suitability for plantation establishment on old field sites under wastewater irrigation. A secondary objective was to determine the wastewater renovation capacity of the reforested old field.

MATERIALS AND METHODS

Detailed establishment procedures and site description for the 2.1 ha old field were reported earlier (Brockway *et al.*, 1979a). The study area was located 5 km south of the main campus of Michigan State University at East Lansing where gently rolling glacial till, 20 m in depth, overlies a bedrock of Saginaw sandstone. Prior to cultivation, the area supported a beech-maple forest. During the post-cultivation period, a well developed sod and herbaceous layer, including *Solidago*, *Digitaria*, *Agropyron* and *Andropogon* developed on the site. The Miami-Conover-Brookston Alfisol soil catena dominated the site. Annual precipitation averaged 765 mm.

The site was planted in April, 1974, following a preplanting weed control treatment of paraquat-CL (1.1 kg/ha) and simazine (2.2 kg/ha). The nine tree species planted were black cherry *(Prunus serotina* Ehrh.*)*, black walnut *(Juglans nigra* L.*)*, eastern cottonwood *(Populus deltoides* Bartr.*)*, northern red oak *(Quercus rubra* L.*)*, white ash *(Fraxinus americana* L.*)*, tulip poplar *(Liriodendron tulipifera* L.*)*, Scotch pine *(Pinus sylvestris* L.*)*, Norway spruce *(Picea abies* Karst.*)*, and white spruce *(Picea glauca* Voss.*)*. In the first four years following planting, tree rows were annually weeded using glyphosate (1.4 kg/ha) and weeds between rows were mowed semi-annually. Weeds along irrigation lines were controlled with an annual simazine-atrazine treatment. Since 1976, the trees have been side pruned and basal sprouts removed to encourage single stem development.

The experimental design consisted of 14 randomized complete blocks. Each block contained 9 tree species organized in 9 rows, each 63 m long and containing 40 individual trees of a single species, totaling 5040 seedlings in the entire plantation. Seedling spacing was 1.5 m x 2.1 m with each block delineated by intervening irrigation lines. Block 1 was the control, receiving no irrigation, while blocks 2 through 14 were treated twice weekly with municipal wastewater.

Secondarily treated wastewater obtained from the East Lansing Municipal Wastewater Treatment Plant was cycled at the Michigan State University Water Quality Management Facility through a system of four ponds ranging in size from 3 to 5 ha. Water directly from the East Lansing plant plus water back-siphoned from the first pond was delivered to the site by an overhead spray irrigation at a rate of 4 mm/hr, totaling 51 mm/wk for approximately 15 weeks each season over seven years. Average annual nutrient application rates with irrigation were 160 kg total nitrogen, 30 kg phosphorus, and 130 kg potassium per hectare. Nitrogen fraction application rates average 90 kg nitrate and 20 kg ammonia per hectare. Application rates of micronutrients were very low, generally less than 1 kg/ha.

During the initial four years of this study, nutrient cycling dynamics received great attention. Weekly water samples were obtained from sprayheads and suction lysimeters installed to sample soil water at a depth of 61 cm in the soil profile. Water samples were preserved with concentrated sulfuric acid (1 ml/600 ml) or concentrated nitric acid (1 ml/300 ml), stored at 4°C, and analyzed by the Institute of Water Research Laboratory at Michigan State University and the University of Wisconsin. Soil samples were collected following each irrigation season at depths of 0-15, 15-30, 45-60, and 105-120 cm in regularly spaced intervals across the site. Soil samples were air dried, composited by soil series and depth, pulverized and passed through a 2 mm screen. Nutrient analysis was performed at the Michigan State University Soil Chemistry Laboratory and A & L Agricultural Laboratories of Fort Wayne, Indiana. Measurement of seedling nutrient status was conducted each September by collecting foliage samples from all trees in blocks 1 through 10. Foliage samples were composited by row, oven dried at 75°C, ground in a Wiley mill, and passed through a 20 mesh screen. Nutrient concentrations were determined at the Michigan State University Plant Tissue Analysis Laboratory.

Tree seedling growth was measured in the initial four years of this study by destructive methods, requiring total above ground tree harvest to obtain biomass data. One seedling per row was selected, cut at the groundline, oven dried, and weighed to determine biomass of the total tree, stem, and foliage components. During each year of measurement, tree height, basal stem diameter (15 cm above ground), and where possible, diameter at breast height (1.4 m above ground) were recorded in the field.

RESULTS AND DISCUSSION

Seedling Survival and Growth

Tree seedling survival was not enhanced by wastewater irrigation (Table I). Following seven seasons of irrigation, modest survival increases in eastern cottonwood, white ash, and white spruce were noted. Decreased survival of treated seedlings occurred in Norway spruce, black cherry, black walnut, and especially tulip poplar and red oak. The severely reduced survival rates of the latter two species were a result of excessive weed competition. Where weeds were not adequately controlled, irrigation treatment stimulated their growth to the point of physically overwhelming the tree seedlings. Scotch pine survival was unaffected by irrigation. Overall survival rates of the above were similar to those reported by Cooley (1979) for species of the same genera.

Table I

Species Survival After 7 Seasons of Wastewater Irrigation, 1980.

Species	*Seedling Survival* — *Control*	*Seedling Survival* — *Irrigated*
	------%	------
Eastern Cottonwood	70	81
White Ash	97	100
Scotch Pine	97	97
Tulip Poplar	87	57
Black Walnut	78	73
Norway Spruce	100	97
White Spruce	78	97
Black Cherry	95	87
Red Oak	87	54

Table II shows the cumulative growth of plantation trees from 1974 to 1980. Irrigation in that period produced significant increases in height and diameter attainment for eastern cottonwood, white ash, Scotch pine, tulip poplar, and black walnut. Norway spruce and white spruce height growth were unaffected by irrigation. Black cherry and red oak height and diameter growth were found to decrease with irrigation treatment.

Table II

Species Growth After 7 Seasons of Wastewater Irrigation, 1980.

Species	*Height*		*Diameter at Breast Height*		*Basal Stem Diameter*	
	Control	*Irrigated*	*Control*	*Irrigated*	*Control*	*Irrigated*
	----------m----------		------------cm------------			
Eastern Cottonwood	2.21	4.42*	2.3	6.4*	4.1	9.1
White Ash	1.47	2.49*	1.3	2.8*	2.0	3.8*
Scotch Pine	2.03	2.36*	3.3	4.1*	---	---
Tulip Poplar	0.69	2.11*	-0-	2.5*	1.0	4.1*
Black Walnut	1.22	1.45*	-0-	1.8*	2.5	3.3*
Norway Spruce	1.35	1.35	-0-	-0-	---	---
White Spruce	1.04	0.94	-0-	-0-	---	---
Black Cherry	1.50	1.22	1.0	-0-	2.3	1.5
Red Oak	1.75	1.14	1.8	-0-	2.8	1.5

*Significantly greater than control at the 0.05 level.

Wastewater irrigation has been cited in several studies as a silvicultural treatment which ameliorates site conditions for plant growth (Smith and Evans, 1977). Einspahr *et al.* (1972) have demonstrated that in some woody plants, height growth is stimulated primarily by applied water and diameter growth is increased by added nutrients. The tree growth results of this study paralleled those of Cooley (1979), Settergren *et al.* (1974), Sutherland *et al.* (1974), and Post and Smith (unpublished)*. These researchers found that the optimum growth response to wastewater irrigation was exhibited by lowland hardwood species of the genera *Populus* and *Fraxinus*. Moderate growth responses were seen in mesic-site upland hardwoods and poor responses were measured in dry-site pines and oaks. The growth results in this study were not consistent with those of Sopper and Kardos (1973) who reported significant growth increases for oak and white spruce stands irrigated with wastewater. The disparity in results could be ascribed only to the fact that their studies utilized older, well established forest stands while this study examined the growth of newly planted seedlings whose root systems incompletely occupied the old field site.

Irrigation extended the season during which seedling growth could occur. Flushes of growth observed on this plantation extended much later into the summer season for irrigated trees than for controls, presumably the result of favorable soil moisture conditions. Similar findings were reported by Howe (1968) for irrigated ponderosa pine and by Kaufman (1968) for white pine and loblolly pine. When exposed to water stress, these pine seedlings underwent root suberization which precipitated the onset of dormancy. Where water stress was severe, the intercalary regions along each shoot also became dormant.

Seedling Nutrient Concentrations and Total Assimilation

After four years of wastewater irrigation, foliar nutrient levels ranged from low to intermediate, within the tolerable limits reported for these species (Bengtson *et al.*, 1968). Foliar nitrogen concentrations were within the higher portion of that range, however, exceeding 2 percent in most species and reaching 3 percent or more in two of the species (Table III). Irrigated trees generally contained significantly higher nutrient concentrations than unirrigated controls, an indication that the irrigated trees had assimilated nutrients applied in the wastewater. Nutrient dilution

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**D.M. Post and W.H. Smith, unpublished report, School of Forest Resources and Conservation, University of Florida, Gainsville, FL 32601.*

resulting from increased growth in the irrigated group may have accounted for the lack of statistical difference with controls in the concentrations of certain nutrients. Unlike the results reported by Neary *et al.* (1975), no nutrient toxicity or deficiency symptoms were noted among plantation trees.

Leaf biomass and leaf nutrient concentrations, as an index of total tree nutrient assimilation following the 1977 season, are shown in Table IV. Eastern cottonwood and Scotch pine accumulated the greatest nutrient quantities in their foliage followed by white ash. These species would probably concentrate large nutrient reserves in their harvestable woody parts as well. As Kramer and Kozlowski (1960) pointed out, as much as 50 percent of the foliar content of some nutrients is retranslocated into the stem prior to leaf abscission. The remaining species assimilated lesser total nutrients as a result of slower growth rates and a resulting lower biomass.

Seedling Performance and Species Recommendations

The tree species evaluated in this study for wastewater irrigation suitability on old field sites were arranged on an ordinal scale shown in Table V. The performance of each species was based largely upon growth response to irrigation; however, total nutrient assimilation and survival were also considered in the final recommendation.

Eastern cottonwood was found to be "superior" in overall performance to all other species tested and as such is highly recommended for use in wastewater irrigation projects. This result was not surprising, when the hydrophilic nature of this species is considered. White ash, Scotch pine, tulip poplar, and black walnut exhibited "good" performance under wastewater irrigation and are also recommended for wastewater recycling programs. It was noted, however, that tulip poplar may suffer extensive mortality on irrigated old field sites unless weed control is adequate. Norway spruce and white spruce were found to be "marginal" in their performance after seven years of irrigation. Growth benefits on the old field were not discernible and overall nutrient assimilation was portionally diminished. Other forest sites may produce more encouraging results with these species than do old fields. Black cherry and northern red oak exhibited decreased survival and growth and very low total nutrient assimilation with wastewater irrigation. Whether their "poor" performance was a result of weed competition or other biotic interactions, these species are not recommended for reforestation of old fields irrigated with municipal wastewater.

Table III

Foliar Nutrient Concentrations by Species Following Wastewater Irrigation for the 1977 Growing Season (Brockway et al., 1979b).

Species	*N*		*P*		*K*		*Na*	
	C	*I*	*C*	*I*	*C*	*I*	*C*	*I*
	%							
Eastern Cottonwood	1.9	1.9	0.18	0.24*	0.48	0.42	0.05	0.19*
Scotch Pine	2.7	3.0*	0.30	0.32	0.82	0.86*	0.05	0.11*
White Ash	2.5	2.5	0.25	0.26	0.52	0.97*	0.05	0.07
Norway Spruce	2.0	2.6*	0.40	0.39	1.00	1.23*	0.06	0.13*
Black Walnut	2.0	2.2*	0.19	0.19	0.66	0.52	0.08	0.23*
Tulip Poplar	1.8	1.8	0.05	0.08*	0.66	0.65	0.06	0.13*
Black Cherry	2.5	2.5	0.20	0.19	0.62	0.57	0.04	0.09
Red Oak	2.0	2.0*	0.32	0.22	0.68	1.03*	0.04	0.16
White Spruce	2.4	3.2*	0.40	0.26	0.88	1.37*	0.07	0.36*

Species	Ca		Mg		B		Mn		Zn	
	C	I	C	I	C	I	C	I	C	I
	--------------%		----------------		-----------------mg/kg		-------------------			
Eastern Cottonwood	0.78	1.12*	0.14	0.16	13.7	42.1*	172	185	35	36*
Scotch Pine	2.20	1.36	0.38	0.40	17.4	21.1*	279	174	35	29
White Ash	0.71	1.11*	0.38	0.36	22.0	40.1*	136	92	13	18
Norway Spruce	0.93	0.91	0.40	0.41	53.6	54.4	157	96	35	37
Black Walnut	0.93	1.15*	0.13	0.18*	28.4	54.2*	386	180	26	13
Tulip Poplar	0.61	0.81*	0.15	0.12	22.0	35.2	107	140	24	6
Black Cherry	0.66	0.55	0.23	0.32*	46.1	45.6	253	367	11	11
Red Oak	0.81	1.18*	0.30	0.23	22.0	25.9*	38	29	40	27
White Spruce	0.86	1.27*	0.50	0.39	39.6	42.8	52	71	51	35

* = Significantly greater than control at the 0.05 level.

C = Control

I = Irrigated

Table IV

Foliar Nutrient Concentration and Content by Species After 4 Years of Wastewater Irrigation, 1974-1977 (Brockway et al.*, 1979b).*

Species	*Leaf Biomass*	*Concentration*							
		N		*P*		*K*		*Na*	
	*gpt**	*%*	*gpt*	*%*	*gpt*	*%*	*gpt*	*%*	*gpt*
Eastern Cottonwood	940	1.3	17.9	0.24	2.3	0.42	3.9	0.19	1.8
Scotch Pine	441	3.0	13.2	0.32	1.4	0.86	3.8	0.11	0.5
White Ash	149	2.5	3.7	0.26	0.4	0.97	1.4	0.07	0.1
Norway Spruce	127	2.6	3.3	0.39	0.5	1.23	1.6	0.13	0.2
Black Walnut	126	2.2	2.8	0.19	0.2	0.52	0.6	0.23	0.3
Tulip Poplar	136	1.8	2.5	0.08	0.1	0.65	0.9	0.13	0.2
Black Cherry	75	2.5	1.9	0.19	0.1	0.57	0.4	0.09	0.1
Red Oak	93	2.0	1.9	0.22	0.2	1.03	1.0	0.16	0.1
White Spruce	48	3.2	1.5	0.26	0.1	1.37	0.7	0.36	0.2

Species	Concentration									
	Ca		Mg		B		Mn		Zn	
	%	gpt	%	gpt	mg/kg	mg PT**	mg/kg	mg PT	mg/kg	mg PT
Eastern Cottonwood	1.12	10.5	0.16	1.5	42.1	39.6	185	174.9	36	33.8
Scotch Pine	1.36	6.0	0.40	1.8	21.1	9.3	174	76.7	29	12.8
White Ash	1.11	1.7	0.36	0.5	40.1	6.0	92	13.7	18	2.7
Norway Spruce	0.91	1.2	0.41	0.5	54.4	6.9	96	12.2	37	4.7
Black Walnut	1.15	1.5	0.18	0.2	54.2	6.8	180	22.7	13	1.6
Tulip Poplar	0.81	1.1	0.12	0.2	35.2	4.8	140	19.1	6	0.8
Black Cherry	0.55	0.4	0.32	0.2	45.6	3.4	367	27.5	11	0.8
Red Oak	1.18	1.1	0.23	0.2	25.9	2.4	29	2.7	27	2.5
White Spruce	1.27	0.6	0.39	0.2	42.8	2.0	71	3.4	35	1.7

* = grams per tree

** = milligrams per tree

Table V

Species Performance Summary: Increase or Decrease in Growth With Respect to Control Species Over 7 Years.

Species	*Height*	*Diameter at Breast Height*	*Basal Stem Diameter*	*Performance Class*
	----------	%	----------	
Eastern Cottonwood	+100	+178	+122	Superior
White Ash	+69	+115	+90	Good
Scotch Pine	+16	+24	---	Good
Tulip Poplar	+206	---	+310	Good
Black Walnut	+19	---	+32	Good
Norway Spruce	0	---	---	Marginal
White Spruce	-10	---	---	Marginal
Black Cherry	-19	---	-35	Poor
Red Oak	-35	---	-46	Poor

Wastewater Renovation Capacity of the Site

The old field study site provided adequate water renovation for the most troublesome of nutrients, nitrate-nitrogen, and phosphorus. In 1977, nitrate and total nitrogen removal from the applied wastewater approximated 85 percent by the time it had percolated to a depth of 61 cm in the soil profile. This value exceeded that reported by Neary (1974) on similar soils. Phosphorus removal was excellent, exceeding 98 percent.

The values reported here for nitrate and phosphorus were similar to those reported by Leland *et al.* (1978) for a nonforested old field site. This comparison underscores the importance of grasses and associated herbs in renovating land-applied wastewater on old field sites. During the course of this study, the plantation seedlings did not fully occupy the site with their immature root systems and incompletely formed crowns. Although evidence on water and nutrient uptake was obtained, previously established grasses and associated vegetation and soil adsorption were thought responsible for a greater amount of wastewater renovation. As the seedling root systems develop and more fully occupy the site, an increasing proportion of the wastewater renovation in this ecosystem may in the future be attributed to the trees.

SUMMARY

During the seven years following establishment, a conifer-hardwood plantation planted on an old field site in southern Michigan was irrigated with 51 mm of municipal wastewater per week. The suitability of the planted tree species for use in reforesting old field sites under wastewater irrigation was evaluated based upon growth, survival, and nutrient assimilation performance. Eastern cottonwood was found to exhibit superior growth and nutrient assimilation responses to irrigation and is highly recommended for this cultural use. White ash, Scotch pine, tulip poplar, and black walnut exhibited good performance under irrigation and are also recommended. Norway spruce and white spruce were found to be marginal in the above performance categories and while not recommended for use on irrigated old field sites, may prove useable on other forest sites under irrigation. Black cherry and northern red oak exhibited survival and growth rates negatively related to irrigation treatment and are not recommended for reforestation of old field sites irrigated with municipal wastewater.

The old field study site provided adequate water renovation, removal of nitrate-nitrogen, and total nitrogen approximating

85 percent and removal of phosphorus exceeding 98 percent. These values were similar to those reported for an unforested old field, underscoring the importance of grasses and associated herbs in renovating land-applied wastewater where planted seedlings have not yet fully occupied the site. As seedling root systems develop toward more complete site occupancy, a greater proportion of wastewater renovation may be attributed to the trees.

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